EXPLORING THE FRONTIERS OF MAGNETIC RESONANCE IMAGING

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New developments in magnetic resonance imaging are highlighted, including multiecho-multislice high-resolution imaging, special purpose coils, multiplanar imaging, thin slices, hybrid imaging processing, flow imaging, heart gating, paramagnetic contrast material, and wider application of spectroscopy.

Magnetic resonance imaging (MRI) has proven to be a useful diagnostic tool for visualizing the central nervous system, the posterior fossa, and the craniovertebral junction, but computed tomography (CT) remains the imaging modality of choice for high-resolution imaging of the brain and for most body applications. In the July 1984 issue of *Radiology,* Brandt-Zawadzki et al[1] concluded that "CT remains the screening modality of choice when high-resolution, thin-section studies in the pituitary, inner ear, and orbital regions are indicated." There were two reasons for this: (1) technical limitations in the present generation of MRI instruments and (2) insufficient research in body MRI.

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Progress is being made, however, on both fronts. New developments have permitted the introduction of techniques that will become routine features in equipment in the months ahead. Several recent developments are discussed below.

NEW DEVELOPMENTS IN MRI

Multiecho-multislice high-resolution imaging of up to 64 slices will become routine in many systems, permitting the radiologist to do a whole series in one single scan. Contiguous slices (Figure 1, a 2-echo, 16-slice sequence) will reduce the chances of missing lesions.

Special purpose coils are designed to be closely coupled to the area of interest, giving a good filling factor. They are a relatively inexpensive way of obtaining images of very high spatial resolution (in-plane resolution 0.8 mm) even in low- and medium-field systems. Coils can be designed for almost any part of the body: breasts, internal auditory meatus, orbits (Figure 2), knees, cervical spine, and lumbar spine. In fact, musculoskeletal MR imaging with surface coils will prove to be of immense value in the years to come.

Multiplanar images will be particularly useful in brain and spine imaging (Figure 3). The image plane can be tilted from transverse to coronal by adjustment of the gradients to obtain oblique slices at 20, 40, and 60 degrees.

Thin slices are of particular importance in brainwork to avoid partial volume effects. Thin slices are obtained by increasing the slice selection gradient and by reducing the rf bandwidth. Because of the smaller sampling volume, the images tend to be "noisy" unless the number of averages are increased. Figure 4 is a 2 mm SE slice of TE 40/1500.

Hybrid imaging is an image acquisition technique that allows the encoding of multiple views by oscillating the phase-encoding gradients. It is a combination of the two-dimensional Fourier transform and echo-planar techniques. Imaging times have been reduced to one quarter of normal imaging times with no discernible loss of quality. Figure 5A is one of a multislice series of eight done at a standard sequence of TE 80/2000 in 17 minutes. Figure 5B, belonging to a similar series done with the hybrid-acquisition technique, was completed in 4.26 minutes. We are now approaching CT acquisition speed!

Flow imaging could have a tre-

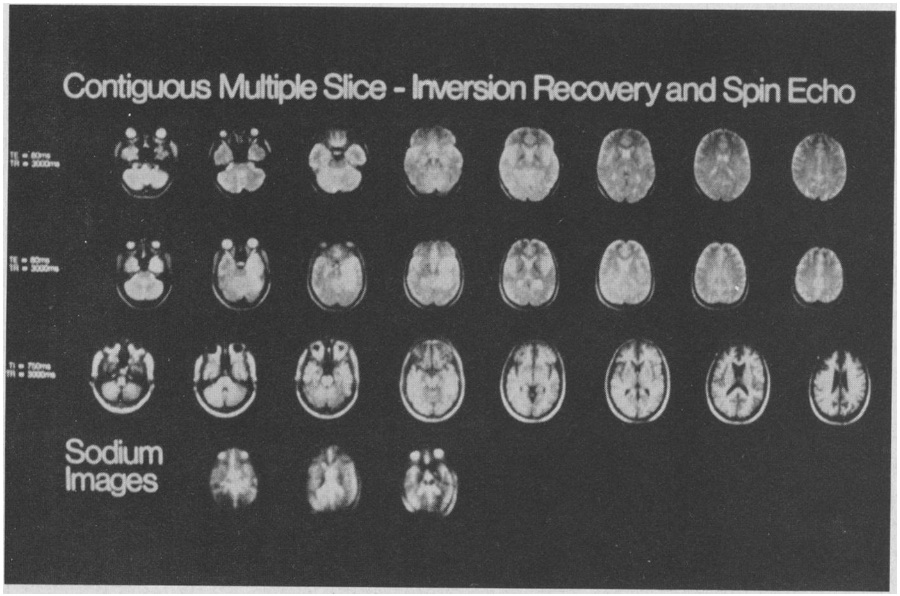

Figure 1. Image showing contiguous slices from a 2-echo, 15-slice sequence. This technique reduces the chance of missing lesions.

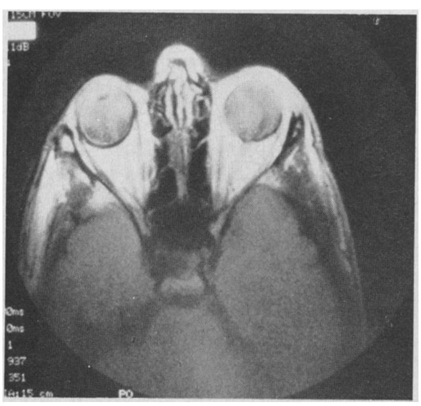

Figure 2. Image of the orbits using special purpose coils.

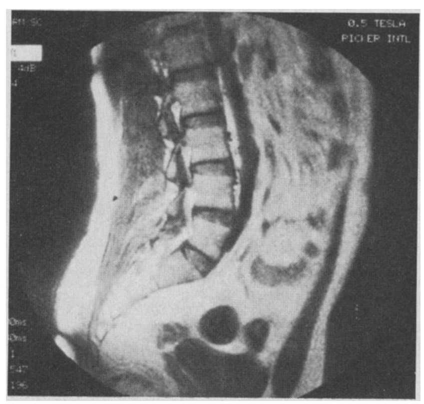

Figure 3. Image of the spine using multiplanar images.

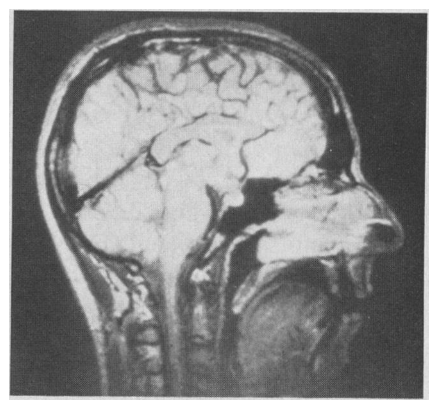

Figure 4. Thin slice of brain (2 mm SE slice of TE 40/1500).

mendous impact on the study of cardiovascular disease. Its major advantage over other methods is that the appearance of flowing blood is different from that of surrounding tissue. The signals from fast flow and slow flow are not the same, because of phase shifts. The phase differences allow one to do velocity profiles that can be shown quantitatively or in color codes.

Heart gating will soon be a reality in MR cardiac angiography, if it is not already. Gated MR of the heart could become the preferred method of diagnosing cardiomyopathies and ischemic heart disease. Figure 6 is from a patient with heart disease. Using the R-R interval as the repetition time, the first R wave is the reference. Continuous slices were then made at any point in the cardiac cycle. The patient has had a recent infarct, perhaps one week old. One can observe an area of decreased intensity in the myocardium, as the site is engorged with fluid.

Also being developed are multiphase techniques for viewing the same slice in different phases at the same time to be displayed in a cine (motion picture) mode. This

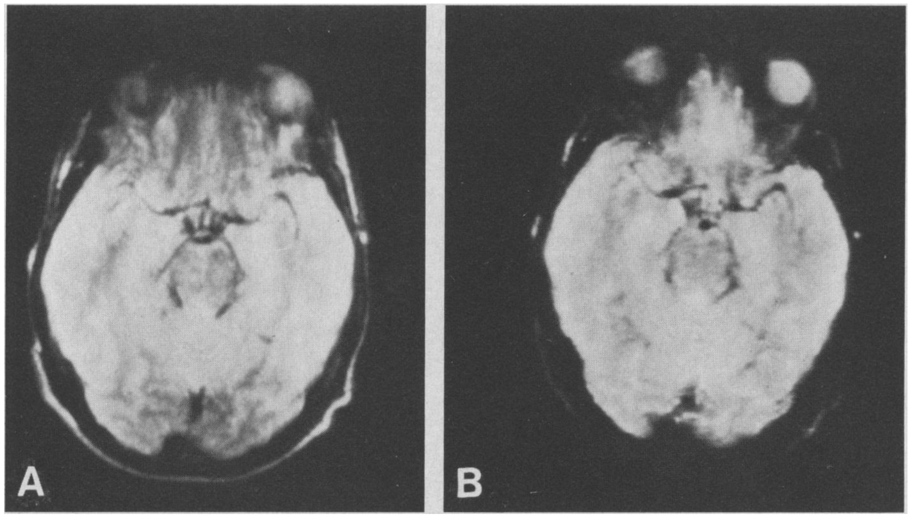

Figure 5. Image of a multislice series of 8 requiring 17 minutes for completion (A). Similar series using the hybrid acquisition technique requiring only 4.26 minutes (B).

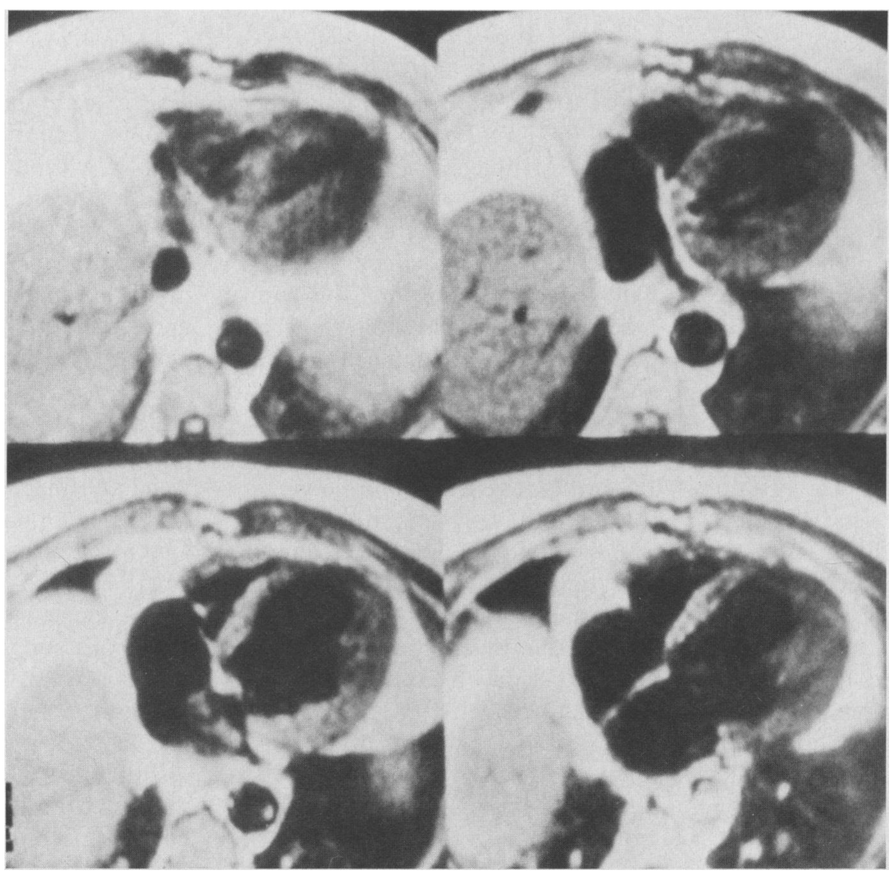

Figure 6. Gated MR of the heart. Note an area of decreased intensity in the myocardium representing engorgement.

Figure 7. Image acquired using the 3 D volume imaging technique. Note the sodium concentration in the cerebrospinal fluid and eyes.

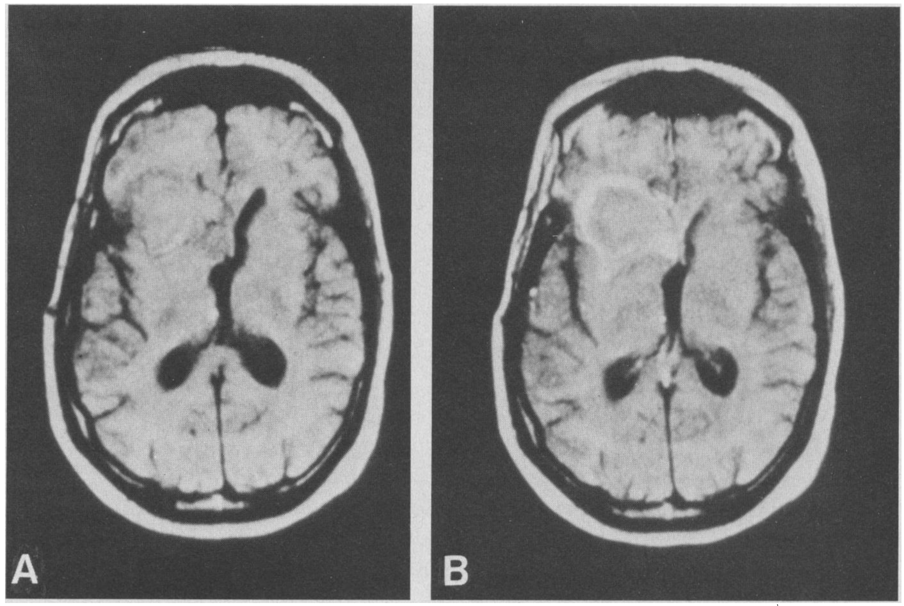

Figure 8. Brain image of a glioma before (A) and after (B) paramagnetic contrast.

will allow the physicians to see heart wall motion and contractility in vivo.

Multinuclear imaging capability in some machines will allow the physicians to image nuclei other than those of the now-customary hydrogen. Sodium is the next most abundant magnetic nucleus in the body after hydrogen, although it is found in very low concentrations (millimolar concentration vs 100 molar for hydrogen proton; only 3 to 6 oz of sodium in the human body). Sodium imaging might prove to be a sensitive physiologic marker for identifying stroke and epileptogenic foci. It may also be used as a screening device for cancer because intracellular sodium concentration in malignant cells is 350 percent higher than in normal cells. However, researchers have not yet been able to demonstrate that sodium imaging can conclusively differentiate intra- from extracellular sodium.

Sodium has very short relaxation times, and therefore one must image with the shortest possible echo delay to achieve reasonable signal strength. The three-dimensional (3D) Fourier transform method of imaging is used to get signals from the whole volume because of the low sensitivity. Figure 7 is one of the 16 slices acquired with the 3D volume imaging technique in a 1.5 T magnet at a frequency of 16.9 MHz. The pulse sequence is TE 10/100, 32 averages. The in-plane spatial resolution is 4 × 4 mm and the slice thickness is 1.5 cm. Notice the sodium concentration in the CSF and in the eyes.

Paramagnetic contrast agents are being researched in many centers. Gadolinium chelated with DTPA (diethylenetriamine pentaacetic acid) has been the most successful to date. At our clinical research site at Hammersmith Hospital, London (UK), gadolinium has been useful in distinguishing tumor from edema. In the United States, it is thought to be useful only in diseases with rich capillary beds where tissue composition remains intact, as in meningiomas. These lesions cannot be easily detected by MR without contrast. More research is continuing to find other media that will help increase the specificity of MRI. The difference in a brain image of a glioma before and after paramagnetic contrast can be seen in Figures 8A and 8B.

Spectroscopy is a noninvasive method for studying metabolites, but its clinical usefulness to date remains uncertain. Most studies have used a phosphorus 31 nucleus. Our research is focusing on hydrogen 1 because of the greater abundance and sensitivity. Water and fat peaks are suppressed; then a technique is used to decouple the CH (lactate) signal from the fat peak. As lactate accumulates with ischemia, this could be of potential value. Attention is now being focused on techniques that could be employed not only in high-field systems, but also in mid-field "workhorse" imaging systems.

CONCLUSIONS

MRI has come a long way in the last year in terms of its acceptance as a useful diagnostic tool. More progress will be made this year and the year after. The quotation from the Brant-Zawadzki article, cited earlier, emphasizes this point. One year later, Brant-Zawadzki (University of California, San Francisco) stated "With the advent of thin slices and high resolution MR scanning we now believe that proton imaging is the optimal screening technique for the detection of most brain abnormalities even when you're looking for pathology in the pituitary or orbital regions."

Tomorrow, MR might be the method of choice for musculoskeletal imaging and cardiac imaging; next year, who knows?

Literature Cited

1. Brant-Zawadzki M, Norman D, Newton TH, et al. Magnetic resonance of the brain; the optimal screening technique. Radiology 1984; 152:71-77.